Plate Based Fuel Processing System

David Yee
Catalytica Energy Systems, Inc.
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Project Objectives

- Develop new catalytic reactor designs and reactor technology for processing gasoline to PEM quality H_2
  - Develop improved catalyst materials compatible with these reactor systems
- Design and fabricate prototype units for each reactor at the 2 to 10kW(e) scale
  - Demonstrate steady state and transient performance
  - Evaluate rapid start up performance

Budget

- Total Funding

DOE Funding	$ 8.16 million
CESI Funding	$ 3.50 million
Program Total	$11.66 million

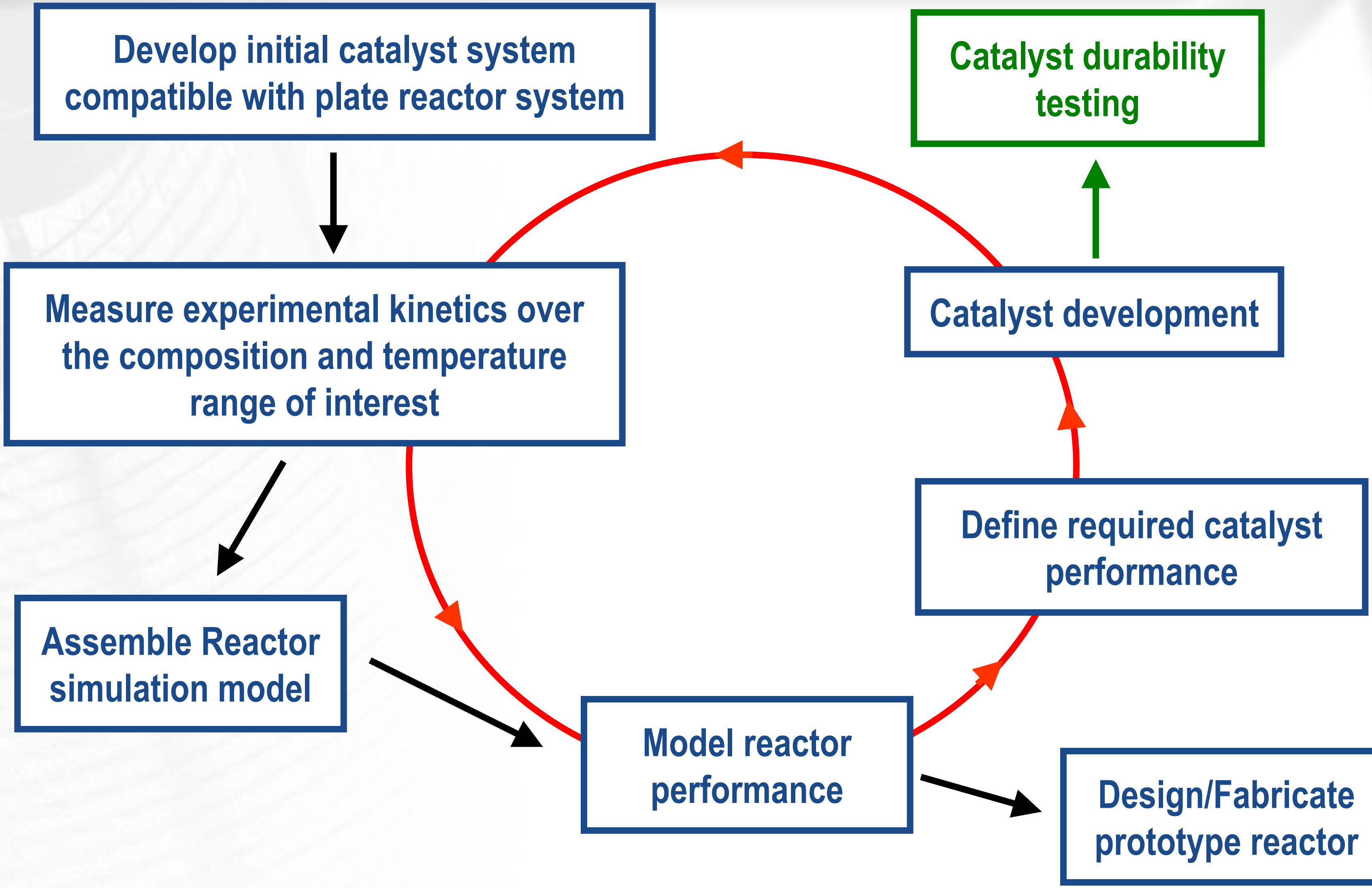
- FY04 Funding

DOE Funding	$ 2.11 million
CESI Funding	$ 0.91 million
FY04 Total	$ 3.02 million

Technical Barriers and Targets

- DOE Technical Barriers for Fuel-Flexible Fuel Processors
  - I. Fuel Processor Startup/Transient Operation
  - J. Durability
  - L. Hydrogen Purification/Carbon Monoxide Cleanup
  - M. Fuel Processor System Integration and Efficiency
  - N. Cost
- DOE Technical Targets for Fuel-Flexible Fuel Processors in 2010
  - Energy efficiency 80%
  - Power density 800 W/L
  - Specific power 800 W/kg
  - Cost $10/kWe
  - Cold startup time to maximum power < 1 min at –20°C (< 0.5 min at +20°C ambient)
  - Durability 5000 hours
  - CO content in product stream < 10 ppm steady state (< 100 ppm transient)

Approach


Develop initial catalyst system compatible with plate reactor system
Measure experimental kinetics over the composition and temperature range of interest
Assemble Reactor simulation model
Model reactor performance
Define required catalyst performance
Catalyst development
Catalyst durability testing
Design/Fabricate prototype reactor

Project Timeline

✓ Start program

✓ Established design criteria for plate reformer with LCF life > 100,000 cycles

✓ Demonstrated required reforming catalyst performance on DOE approved Benchmark Fuel I with 10ppm S

✓ Shake-down and testing of reformer prototype

Demonstration of WGS and PrOx prototype reactors

2001	2002	2003	2004	2005

✓ Validated test rig simulating plate reactor configuration

✓ Complete prototype reformer fabrication

Program completion

✓ Stable & non-pyrophoric WGS catalyst demonstrated / kinetics measured

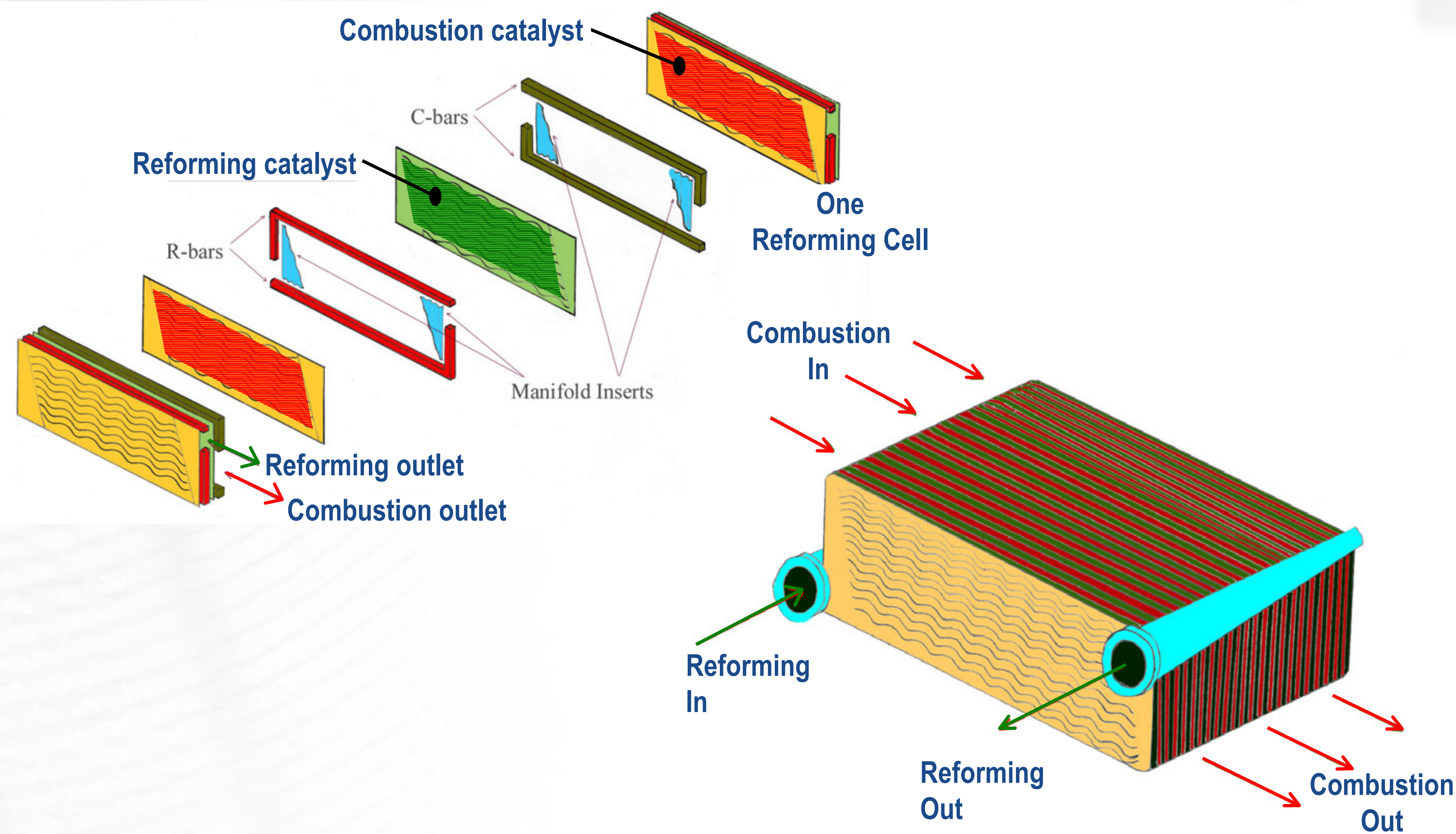
2nd and 3rd generation reformer prototype designs

Fuel Processing Approach

Gasoline	Tier 2, 30 ppm sulfur (average) gasoline
↓	
Steam reforming	Process heat provided by catalytic combustion of gasoline or anode purge gas (outlet ~70% H_2 & 16% CO dry basis)
↓	
H_2S removal	Absorption trapping—required level to be specified (initial target <0.1 ppm S)
↓	
Water gas shift	20% CO at inlet with 80% conversion
↓	
Preferential CO oxidation	1% CO at inlet with <10 ppm CO at outlet
↓	
PEM quality H_2	

CESI Reactor Approach

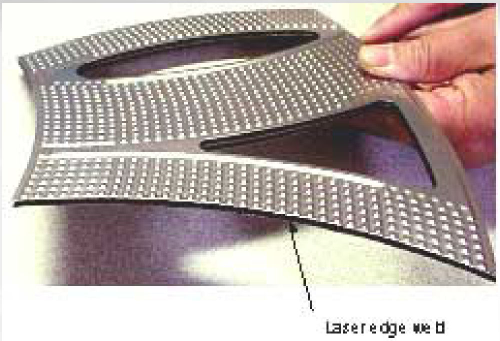
- Major components based on plate-type heat exchangers

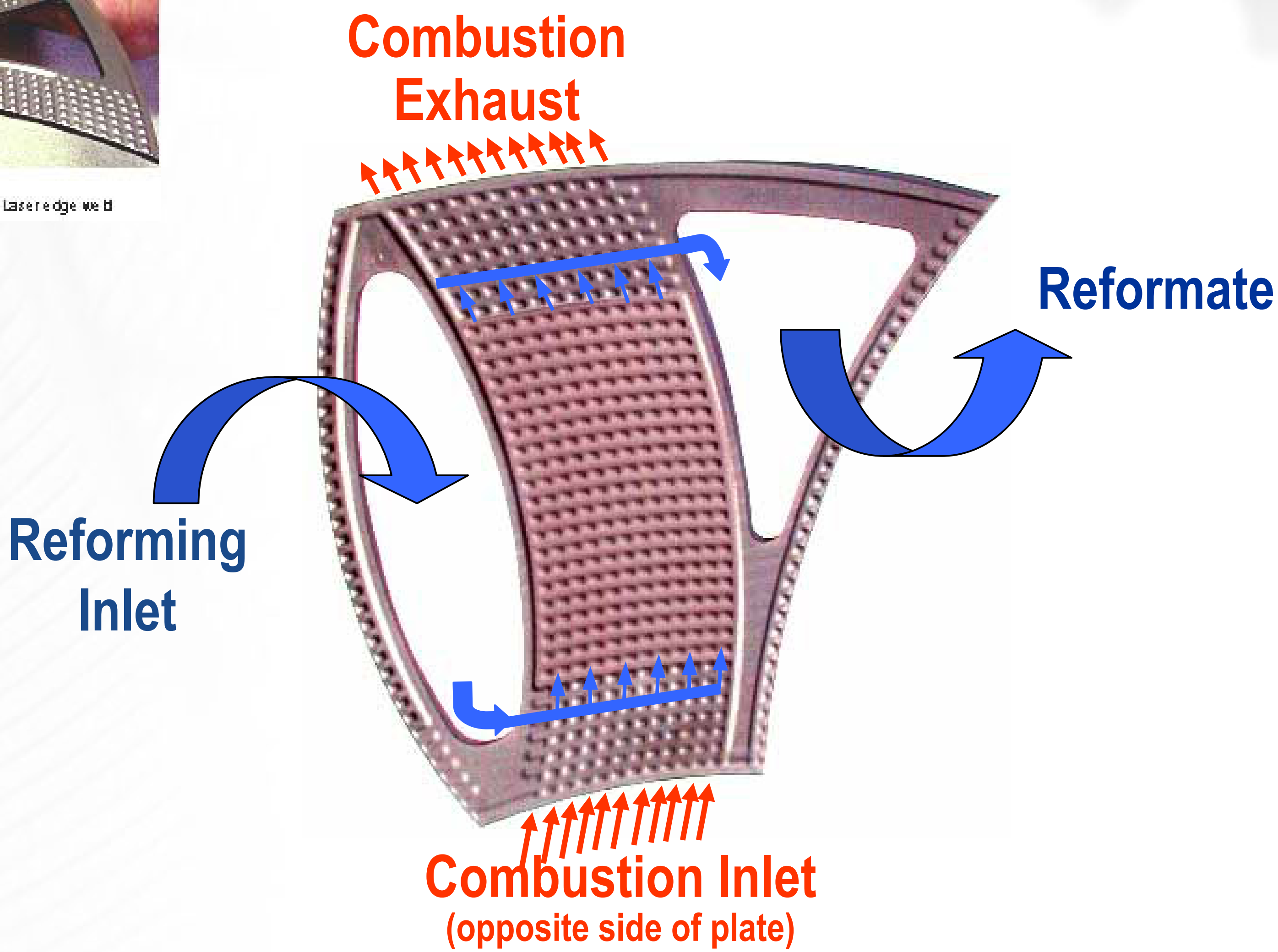


First Steam Reformer Prototype Fabrication

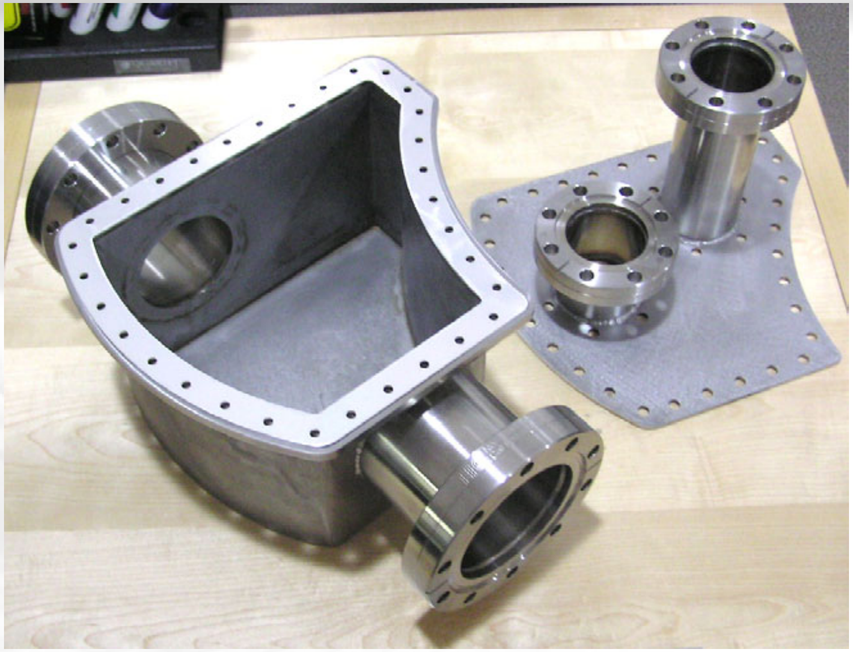
- Utilize plates from an existing heat exchanger design from a gas turbine recuperator (7.5 mil = 0.2 mm thick).
- Cut one-tenth sector (shaded region) to fabricate a simple prototype.
  - Reaction area per plate is small (5.5 by 15 cm) requiring significant number of plates to achieved desired output.
- Utilized CESI coating knowledge to successfully develop a coating process.
- Developed a plate welding process.

Plate Reactor Design

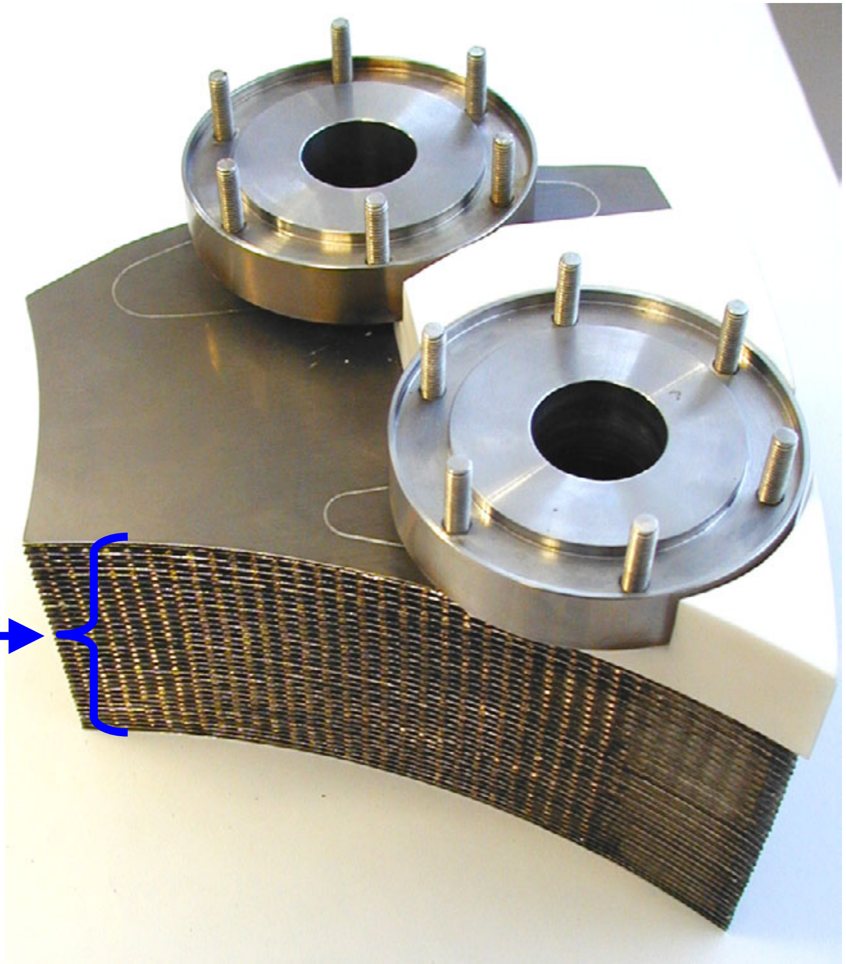




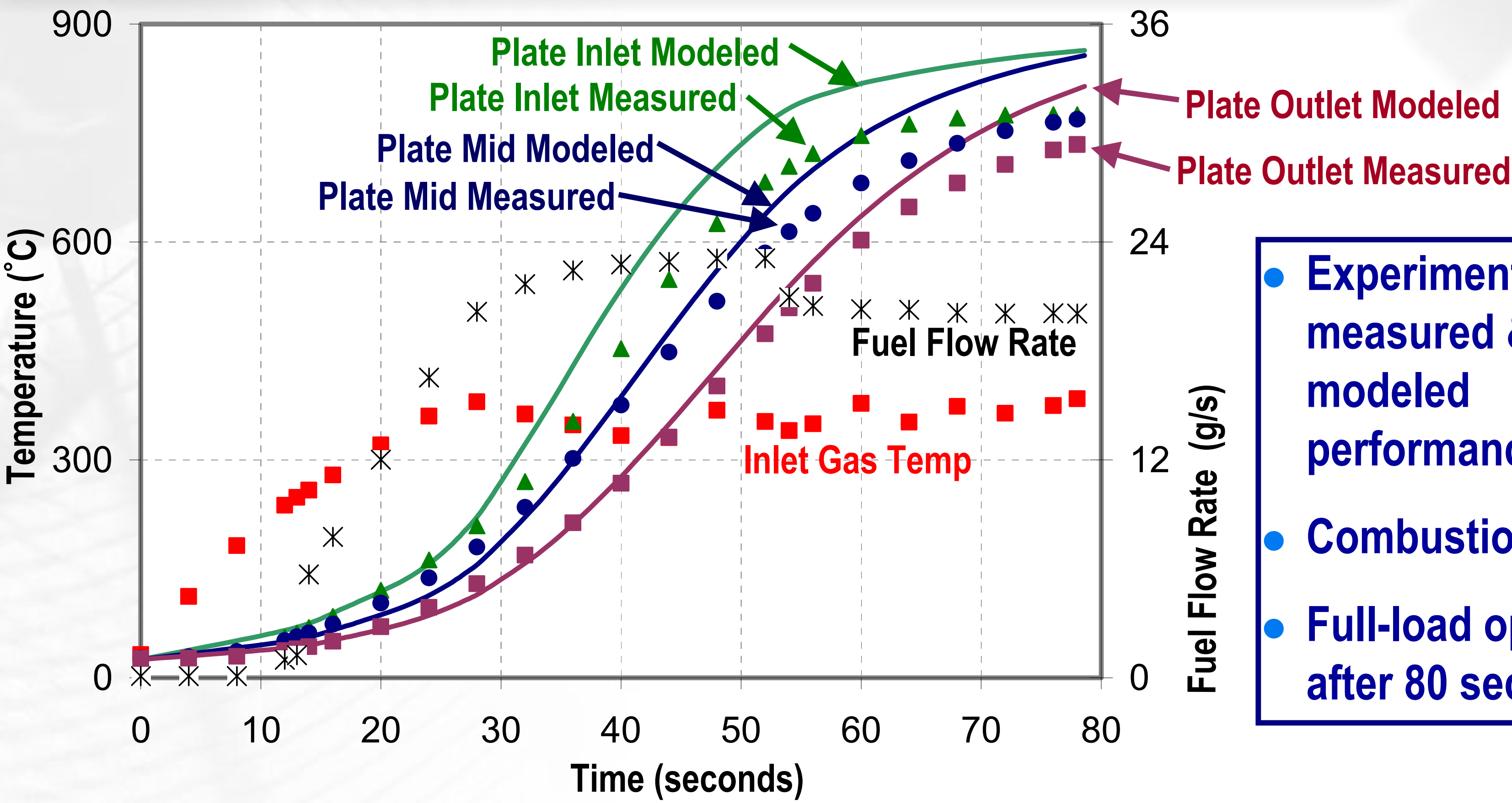
3 kW(e) Prototype Hardware



3 kW(e) = 32 plate pairs = 7.3 cm



3 kW(e) Prototype Performance



- Experimentally measured & modeled performance
- Combustion only
- Full-load operation after 80 seconds

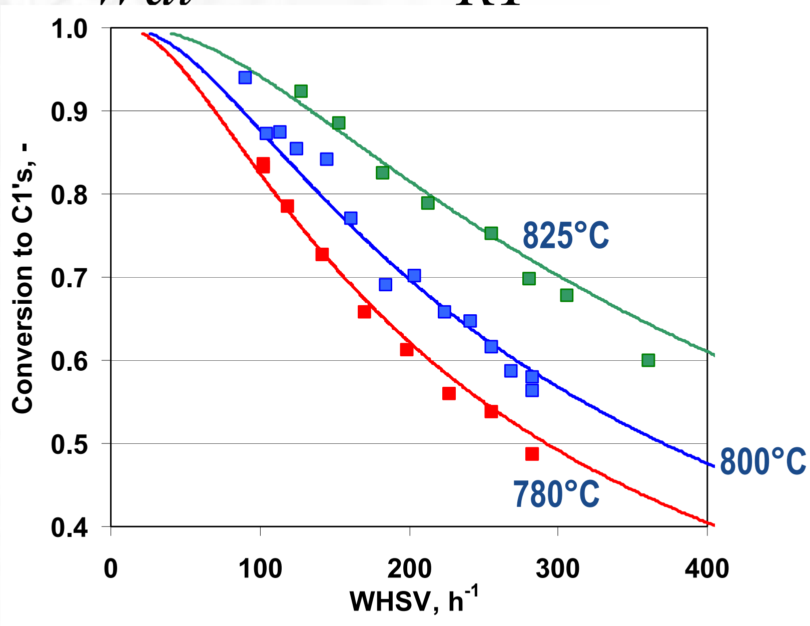
Steam Reformer start-up achieved within 80 seconds

Experimental data validates predictive model

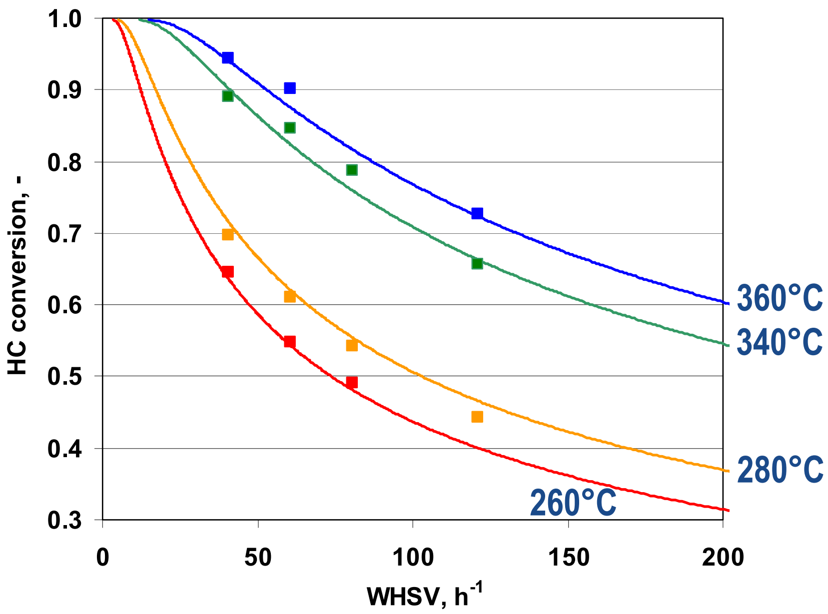
Reforming & Combustion Catalysts Kinetic Model

- Experimentally determined kinetics to support modeling effort

$$r = \frac{dN_{C1}}{Wdt} = k_0 \cdot \exp\left(\frac{-E_A}{RT}\right) \cdot y^{a}_{C8}$$



$$r = \frac{dC_{HC}}{Wdt} = k_0 \cdot \exp\left(\frac{-E_A}{RT}\right) \cdot y^{a}_{HC} \cdot y^{b}_{O2} \cdot y^{c}_{CO2}$$



Power rate law expression fits experimental data

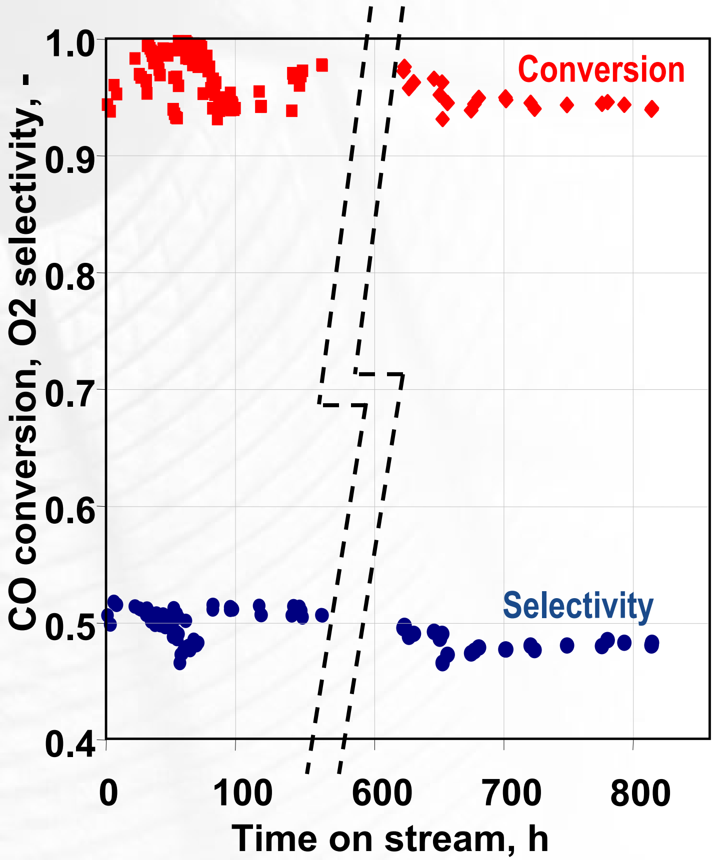
Water Gas Shift

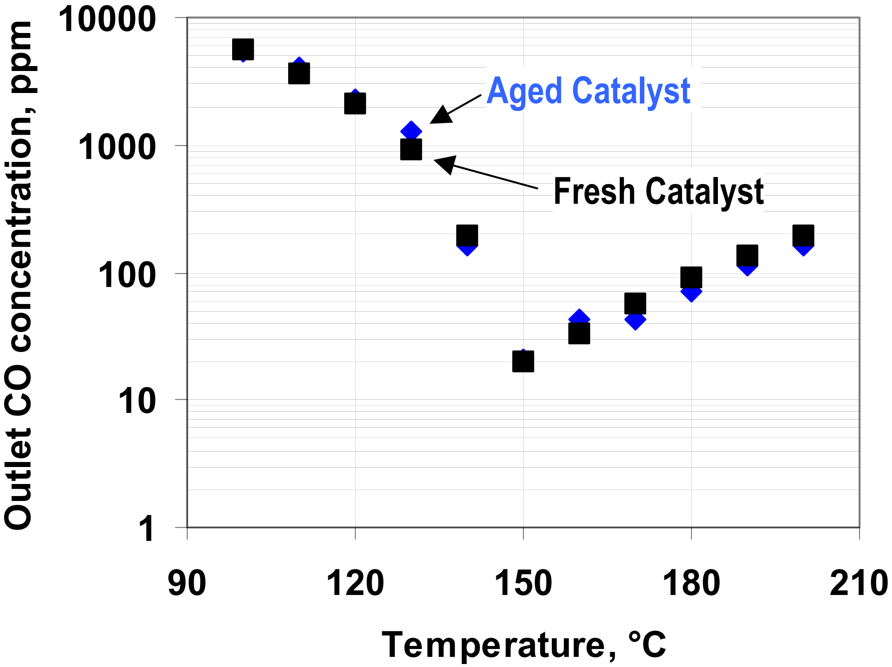
- Modeled parameters to reduce WGS reactor volume
  - All plate reactor based designs
  - Kinetics based on experimental measurements

	Range Studied	Base Case	Optimized Case
Number of stages	1 or 2	1	1
Flow Pattern	Co or counter current	Co-current	Co-current
Molar Flow Ratio (cooling/reformate)	0.5 to 2.0	2.0	1.5
Inlet Temperature	235°C to 295°C	275°C	250°C
CO Abatement	80% to 90%	90%	80%
Catalytica WGS Volume		36.1 L	19.1 L

WGS volume reduced by 47% to 19.1 L for 50 kW(e)

800-hour PrOx Catalyst Durability Test





Constant WHSV

No degradation of catalyst performance after 800 h on stream

System Performance

- Current CESI's system performance *versus* DOE targets

		2010 target	2005 target	CESI 2004	Comments
Energy efficiency	%	80	78	75	integrated heat management calculated from PRO/II SimSci software
Power density	W/L	800	700	1,650	reactor components only
Specific power	W/kg	800	700	1,400	reactor components only
Cost	$/kW(e)	10	25	21	precious metal costs only
Cold start-up time	s	60	120	80	steam reformer start-up only
Durability	h	5,000	4,000	> 5,000	thermal stress analysis

Interactions and Collaborations

- Argonne National Laboratory
  - Ted Krause – Water Gas Shift catalyst
- Pacific Northwest National Laboratory
  - Greg Whyatt – Microchannel Vaporizer
- Plate Fabricators
  - Several commercial companies
- National Fuel Cell Research Center, UC Irvine
  - Professor Scott Samuelsen – Competitive Technology and Market Assessment for the Production of a Hydrogen-Containing Stream for Use in PEM Fuel Cells

Reviewer's Comments

- Energy costs of starting needs to be addressed
  - Modeled several start-up scenarios
  - Evaluated energy costs of alternative start-up heating scenarios
- Sulfur management critical to all fuel processing options
  - All sulfur compounds are converted to H_2S in the reformer
  - H_2S easily reduced to required level by current commercial technology
- Large size of WGS suggest this should be a focus
  - Modeled alternative reactor configurations to identify performance requirements to significantly reduce WGS reactor volume

Future Work

- Remainder of FY 2004
  - Fabricate and test more commercial plate reactor prototype design
  - Develop more energy efficient start-up strategies
  - Fabricate and test PrOx plate reactor prototype
  - Demonstrate reforming catalyst durability
  - Develop alternative WGS reactor concepts to further reduce reactor volume
- FY 2005
  - Fabricate and test low cost & commercially viable plate reactor prototype design
  - Fabricate and test WGS reactor prototype
  - Demonstrate WGS durability